REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 15 2000	Final, 1 Jan 1996 – 31 Dec 1999

4. TITLE AND SUBTITLE
Toward A Cognitive Theory of Direct Interaction

5. FUNDING NUMBERS
N00014-96-1-0472
N00014-99-1-0255

6. AUTHORS
Jiajie Zhang, Todd R. Johnson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The University of Texas Health Science Center at Houston
Payment and Account Facilitation Team
Post Office Box 20036
Houston, Texas 77225-0036

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research, Code 1141SB
800 N. Quincy Street
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This report is a summary of work done on a project to develop a cognitive theory of direct interaction in the context of dynamic decision retargeting tasks in F/A-18 cockpit. At first, a comprehensive representational analysis was carried out for five navigation instruments (VOR, ADF, RMI, 747 and F/A-18) used in aviation. This analysis generated predictions about the degree of directness of interaction for the five sets of instruments for navigational positioning tasks and more complex retargeting tasks. Several series of experiments were designed to test the predictions and provide data for the refinement of the theory and the development of a computational model. The studies over the project period demonstrate that (a) the cognitive theory of direct interaction can systematically generate theoretical predictions that can be tested in experiments; (b) the methodology of representational analysis is a powerful and systematic tool for the analyses of the real-time retargeting tasks; (c) the Act-R based computational model has promising results; and (d) the analyses of the cockpit navigation instruments can be considered as recommendations for the design of future instruments.

14. SUBJECT TERMS
Direct interaction, user interface, human factors, representation, F/A-18, retargeting, modeling, aviation

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

FINAL REPORT

GRANT #: N000149610472 and N00014-99-0255 (two phases of the same Grant)

PRINCIPAL INVESTIGATOR: Dr. Jiajie Zhang

INSTITUTION: University of Texas at Houston

GRANT TITLE: Toward A Cognitive Theory of Direct Interaction

AWARD PERIOD: 1 Jan 1996 - 31 Dec 1999.

OBJECTIVE: To develop a cognitive theory of direct interaction in the context of dynamic retargeting tasks of F/A-18; to study the user interface issues of F/A-18 cockpit; to develop recommendations of user interface design for F/A-18 cockpit.

APPROACH: We conducted extensive representational analyses of five isomorphic navigation instruments (VOR, ADF, RMI, 747, and F/A-18) for dynamic retargeting tasks in various airplanes. Based on these analyses we used the theory of distributed cognition to predict the directness and representational efficiencies of the five instruments. We performed several sets of experiments of learning and retargeting tasks to test the predictions. Based on the representational analyses and empirical results, we built an Act-R model for a subset of the retargeting tasks.

Accomplishments:

In 1996-1997, we started the project by using Visual Basic to program the cockpit instruments and experiment software in Windows 95 environment. At the same time, we carried out a comprehensive representational analysis of five navigation instruments (VOR, ADF, RMI, 747· and F/A-18). This representational analysis predicted the following directness of the five instruments: 747 = F/A-18 > RMI > ADF > VOR. We performed the first set of experiments that tested and confirmed the prediction. This set of experiments was based on a simple task (the so-called positioning task) in which the subjects used one of the five instruments to locate the position of an airplane from the information available on the instruments.

In 1997-1998, based on the initial experimental work on the simple positioning task we performed in 1996-1997, we designed and carried out several sets of dynamic retargeting experiments for the four of the five instruments: VOR, ADF, RMI, F/A-18. 747 instrument was removed from the list because it was very similar to the F/A-18 instrument. The miniature cockpit for these tasks was implemented in Microsoft Visual Basic. In the retargeting tasks, a pilot first identified his/her horizontal position by using one of the four sets of instruments. Then the pilot was told that an event at a different location needed immediate attention and was given the bearings of the location in relation to his airplane. The pilot's task was to fly the airplane to the new location as quickly as possible. Our first hypothesis is that with different sets of instruments the difficulties of performing the retargeting tasks are different, with a difficulty order of F/A-18 < RMI < ADF < VOR. This difficulty order was confirmed by the results from all sets of experiments. The first set of retargeting experiments focused on the comparison of moving map and fixed map conditions (i.e., pilot-centered and station-centered) with different sets of instruments. In addition to the predicted difficulty order of the instruments, we found that the fixed map version was easier. The second set of retargeting experiments focused on the orientations of the maps, which is either consistent or inconsistent with the heading of the airplane. In addition to the predicted difficulty order of the instruments, we found that the consistent version was easier. The third set of experiments focused on the transfer from one set of instruments to another set. For example, pilots who were trained on VOR method were asked to perform the same tasks with the F/A-18 instruments. The results showed that there was an instrument-independent general transfer.

Based on the experiments described above, we implemented an ACT-R model for the dynamical navigation tasks. Our testing of the model was focused on the simple positioning task. The model's learning behavior matched that of subjects: they both showed a power function of practice.

In 1998, both the PI and the Co-PI moved to University of Texas-Houston from The Ohio State University. After moving-related setup, we performed the following work.

Based on the experimental work we performed before 1998 at Ohio State University, we designed a new set of dynamical retargeting task. In this new retargeting task, a pilot first identifies his/her horizontal position by using one of the four sets of instruments (VOR, ADF, RMI, F/A-18). Then the pilot is told that an event at a different location needs immediate attention and is given the bearings of the location in relation to his airplane. The pilot's task is to fly the airplane to the new location as quickly as possible. Unlike the previous retargeting experiments in which pilots flied the airplane with both instruments and visible map displays, in the current experiment the pilots had to do complete instrument flying, that is, the only information available for the pilot was the readings of a specific instrument (e.g., VOR). This is an extremely challenging task. We tried an early version of this experiment at Ohio State but could not do it because none of the undergraduate students could successfully perform the task. In the new experiment, we simplified the task and recruited subjects from the pool of graduate students at UT Houston. Each subject spent 3 to 4 hours to perform the task. We run 15 subjects for each of the two of the four instruments (VOR, RMI). The result for the two conditions was very clear: the VOR condition was significantly much harder than the RMI condition both for the base-line training task and for the retargeting task afterwards.

We visited the Naval Research Lab at China Lake in January, 1999 and established collaborations with them. They created and ran simplified version of our experiments. We obtained their data. Due to a bug in their computer program, part of data could not be interpreted.

Johnny Chuah successfully defended his master's thesis in Psychology in 1998, and he remained at Ohio State to finish his Ph.D. with another advisor after the PI and Co-PI moved to Houston. Kevin McGrory completed his master's degree in computer science and accepted a job offer at Lucent Technology in 1998.

We are currently preparing two more manuscripts to publish the results obtained from the research supported by this grant. One paper will develop the cognitive theory of direct interaction that was originally proposed for the project. We have collected enough data to support our initial framework of the theory and provide details for the modification of the initial theory. We plan to submit this paper to Human-Computer Interaction. The second paper will be focused on Act-R modeling. We have developed an initial model for the navigation task and tested it for the simple positioning task. We have done initial analysis of the task structures of the complex retargeting task and have enough empirical data to support a full model. We plan to submit this paper to Cognitive Systems.

Conclusions:

This project uses dynamic retargeting in the F/A-18 as the task domain and testbed to (a) develop a cognitive theory of direct interaction that will explain and predict the basic phenomena of direct interaction and will provide a set of principles that specify how to achieve direct interaction; (b) develop a methodology of representational analysis that will provide a set of procedures for the analysis and comparison of direct and indirect systems; (c) develop a computational model that will make detailed behavioral predictions on interface usability and learnability for a variety of interface tasks; (d) perform detailed representational analyses for the key instruments and displays used for retargeting tasks.

The studies over project period demonstrate that (a) the cognitive theory of direct interaction can systematically generate theoretical predictions that can be tested in experiments; (b) the methodology of representational analysis is a powerful and systematic tool for the analyses of the real-time retargeting tasks; (c) the Act-R based computational model has promising results; and (d) the analyses of the cockpit navigation instruments can be considered as recommendations for the design of future instruments.

The major scientific significance is the development of a cognitive theory and a computational model of direct interaction. The major military significance is the redesign of F/A-18 cockpit instruments such that they provide direct interaction with the pilots who can spend their limited cognitive resources to other critical tasks (e.g., fighting). The major commercial significance is the development of guidelines of direct interaction user interfaces that can help the design of general software.

Patent Information: NONE

Award Information: The PI (Jiajie Zhang) and Co-PI (Todd R. Johnson) were promoted to Associate Professor from Assistant Professor. Johnny Chuah, a graduate student fully supported by this grant, won a Summer Cognitive Science Fellowship from The Ohio State University. Hongbin Wang, another graduate student partially supported by this grant, won the Marr Prize for his work on another ONR sponsored project, and he was offered an Assistant Professor position in the Department of Health Informatics at University of Texas at Houston.

Publications and Abstracts:

1. Zhang, J. (1997). Distributed representation as a principle for the analysis of cockpit information displays. *The International Journal of Aviation Psychology,* 7, 105-121.

2. Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*, 179-217.

3. Zhang, J., Johnson, T. R., Chuah, J., & McGrory, K. (1997). (Abstract) Direct Interaction Representation of Cockpit Information Displays: The Tradeoff between Internal and External Representations. *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society (pp. 1097)*. Hillsdale, NJ: Erlbaum.

4. Chuah, J. (1998). *Distributed cognition in aviation navigation tasks*. Master's Thesis. Department of Psychology, Ohio State University.

5. Chuah, J., Zhang, J., & Johnson, T. R. (1998). (Abstract) Distributed cognition of a navigational Instrument display task. *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Erlbaum.

6. Zhang, J. (1998). A distributed representation approach to group problem solving. *Journal of American Society of Information Science, 49*(9), 801-809.

7. Zhang, J., Johnson, T. R., & Wang, H. (1998). Isomorphic representations lead to the discovery of different forms of a common strategy with different degrees of generality. *Proceedings of the Twentieth Annual Conference of the Cognitive Science Society (pp.* Hillsdale, NJ: Lawrence Erlbaum.

8. Chuah, J., Zhang, J., & Johnson, T. R. (2000). The Representational effect in complex systems: A distributed representation approach. *Proceedings of the 22th Annual Conference of the Cognitive Science Soceity*. Hillsdale, NJ: Erlbaum.

9. Zhang, J. (in press). External representations in complex information processing tasks. In A. Kent (Ed.), *Encyclopedia of Library and Information Science (Vol. 00, 000-000)*. New York: Marcel Dekker, Inc.

10. Zhang, J., & Wang, H. (in review). The effect of external representations on numerical tasks. Manuscript submitted to *Mathematical Cognition*.

11. Zhang, J. (in preparation). External representation: The Medium of the Interaction between Cognition and Technology. Book manuscript under preparation. (Part of Cognition and Technology Series: Editor, Alan Lesgold).